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JOINT VISION 2010 AND THE OPERATIONAL COMMANDER: IS GPS A DOUBLE-EDGED SWORD?

by

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The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

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This paper addresses the vulnerabilities created by GPS proliferation in the operational concepts of *JV 2010*. To emphasize this point, the first three concepts are examined in the context of a conflict where the GPS signal is not available in the operational commander's battlespace. GPS proliferation is then viewed from the perspective of the enemy in the operational concept of *full dimensional protection*. That is, the "switch is turned back on" and the enemy can also use GPS. Finally, recommendations are made to reduce the critical vulnerabilities pointed out in the first three *JV 2010* concepts, and the threats posed by a GPS-equipped enemy in the concept of *full dimensional protection*.

GPS is truly a double-edged sword. The United States must not rely too heavily on this one technology in its vision for future forces. Should GPS capabilities be denied, the options available to the operational commander of 2010 could be grievously reduced. Concurrently, the capabilities of a GPS-equipped foe must be planned for. The future commander will face an enemy with targeting capabilities similar to his own. We must plan now for a military future with GPS. We must be keenly aware, however, of this technology's ability to cut both ways as a "double-edged sword."

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"Undoubtedly, it is wrong to let technology alone dictate the shape of a given tactical concept that, in turn, will be used to build operational and strategic concepts. It is just the other way around."[1]

Dr. Milan Vego

"By 2010, we should be able to change how we conduct the most intense joint operations. Instead of relying on massed forces and sequential operations, we will achieve massed effects in other ways. Information superiority and advances in technology will enable us to achieve the desired effects through the tailored application of joint combat power."[2]

Joint Vision 2010

Technology is seductive. Like the sirens in Homer's *Odyssey*, it can entice the unwitting explorer into perilous waters. Today, the United States' military is exploring the uncharted waters of the next decade and a half in the seminal document *Joint Vision 2010*. As the two quotes above show, technology can sometimes be seen as a solution in itself. *Joint Vision 2010* relies heavily on technological advances to shape its core operational concepts of *dominant maneuver, precision engagement, full dimensional protection,* and *focused logistics.*[3] Admiral William Owens' concept of a "system of systems" underpins *JV 2010's* technological assumptions for the future.[4] The synergistic effect of many technologies is envisioned as a force multiplier that will allow future commanders to amass lethal firepower, while endangering fewer friendly forces.

The "system of systems" relies on three core technologies: digitization, computer processing, and global positioning.[5] In fact, the Global Positioning System (GPS) is pervasive in the future system of systems.[6] Although this system is not specifically named by Admiral Owens, it is the only precision navigation system currently available to U.S. forces, and will continue to be the system in 2010.[7] Admiral Owens singles it out for its profound effect on the *JV 2010* operational concept of *precision engagement*: ". . . global positioning allows precise, real-time location and targeting of anything tangible."[8] The Admiral's deep faith in GPS refers

to only one of the four operational concepts. In fact, *all four* of the competencies are intimately intertwined with the Global Positioning System.

GPS has been called the ultimate dual-use technology. Indeed, this is an accurate description. It can provide the operational commander with real-time battlespace awareness--when the system is working properly. The first three operational concepts find GPS so pervasive in their architecture that its loss could be catastrophic, hence making GPS a critical vulnerability for the commander of 2010.[9] GPS is vulnerable to jamming.[10] Additionally, the possibility of physical destruction of parts of the system by a foe in 2010 should not be ruled out.[11] The role played by GPS in the operational concept of *full dimensional protection* can also be classified as a critical vulnerability, but it is more instructive to analyze GPS as an enemy force multiplier and view "the other blade" of this technological "double-edged sword."

The purpose of this paper is to show that the pervasiveness of GPS in the construct of *Joint Vision 2010* creates a critical vulnerability in the operational concepts of *dominant maneuver, precision engagement,* and *focused logistics*, while the proliferation of GPS technology in general creates exceptional challenges for the operational commander in the area of *full dimensional protection.*

Dominant Maneuver

Southwest Asia, 2010: General Orion Rockwell simply couldn't believe it. After the initial success of Operation DESERT RETURN, who could have guessed that the situation in his theater could deteriorate so rapidly? The elimination of the enemy's Integrated Air Defense System (IADS) by "information warriors" on the first day of the war was right out of Joint Vision 2010, but currently his forces simply could not maneuver. GPS was down. It was hard to believe, but true. The maneuver warfare of DESERT STORM was supposed to pale in comparison to General Rockwell's operational plan, but the reality was quite the opposite.

General Rockwell's predicament, while fictitious, is not totally unrealistic. In future conflicts, should the GPS signal be altered or denied to U.S. forces, the ubiquity of GPS-based military

systems will limit the commander's ability to apply the operational concept of *dominant maneuver* effectively. *Joint Vision 2010* defines dominate maneuver as:

> ". . . the multidimensional application of information, engagement, and mobility capabilities to position and employ widely dispersed joint air, land, sea, and space forces to accomplish the assigned operational tasks."[12]

The very definition of *dominant maneuver* hinges on precise positioning capability--the capability provided by GPS. The ability to maneuver quickly and precisely may be significantly degraded in a GPS-hostile environment because of some GPS related problems: degraded or inoperative navigational systems; reduced capability in combat identification (ID), and degraded readiness in basic navigational skills.

The successful use of GPS in Operation DESERT STORM sent the world's armed forces scurrying to the nearest defense contractor to purchase as many GPS receivers as possible. Although only 13 satellites were operational when DESERT SHIELD forces deployed in August of 1990, the system's performance was an unmitigated success.[13] In the afterglow of DESERT STORM, the U.S. Central Command's Army Component Commander (USARCENT), Lt. General John Yeosock declared GPS "indispensable" and called for equipping every tank with a GPS receiver.[14] As of the fall of 1995, every U.S. Navy surface ship and submarine, with the exception of six units slated for decommissioning, were GPS-equipped.[15] It is important to note that GPS is not the *sole* navigation system in most weapons platforms. It does, however, greatly improve the capabilities of current inertial navigation systems (INS). In tactical jet aircraft for example, an INS/GPS combination is used.[16] Although the GPS signal is not the only source of navigation information in this system, it is tightly woven into the navigation infrastructure, hence rendering navigation and weapons employment susceptible to GPS signal interruption or manipulation. In 1993, the Department of Defense (DOD) purchased 94,000 Precision Lightweight GPS Receivers (PLGRs) from Collins Electronics.[17] This hand-held GPS receiver

furnishes the foot soldier with precise positioning data. Hence, GPS is everywhere; it has trickled down to the individual foot soldier. Each soldier will not necessarily have his own GPS, but every maneuvering element will. With this extensive system proliferation, the potential for widespread effects on navigation during maneuver is daunting. The potential for integrating GPS into future combat identification (ID) systems could also affect the battlefield of 2010.

Dominant maneuver, by definition, requires "widely dispersed joint air, land, sea, and space forces to accomplish the assigned operational tasks."[18] Widely dispersed forces challenge the operational commander's ability to maintain "situational awareness," and in the most extreme case, prevent fratricide. Not surprisingly, GPS technology is entering the combat identification arena also. GPS will allow the operational commander to expand his "battlespace" and approach Admiral Owens' goal of dominant "battlespace awareness."[19]:

> "Combat identification (ID) has long depended on line-of-sight radio systems such as Mode 4 IFF (identification friend or foe). The use of space-based assets such as GPS removes this restriction, bringing major advances in battlefield management and situational awareness."[20]

As long as a GPS signal is available, this advance in combat ID affords the operational commander incredible situational awareness. *International Defense Review* boasts, ". . . a commander traveling by car could follow tracks in real time from a distance of up to 10,000 km, using only the [Situational Awareness Beacon with Reply (SABER)] beacon, a laptop computer and a small UHF antenna."[21] SABER technology goes a step further, integrating "point and shoot" capabilities into the system. That is, any platform integrated into the system could "interrogate" a potential target in the battlespace and transmit an "intent to kill" message. SABER would ID the target, ensure weapons radius clearance around it, and authorize weapons release--all within seconds.[22] Rules of engagement questions aside, lack of GPS in a lethal, futuristic system such as this would surely change the operational commander's conduct of the

war. This same commander will have to rely on the basic skills of his people, should someone "pull the plug" on GPS.

Will the armed forces experience a degradation in navigational skills by 2010? Increased reliance on GPS in navigational aids (NAVAIDs) suggests this. General Patrick Cordingley, Commander, British Seventh Armored Brigade recalled his force's reliance on GPS for navigation during the Gulf War:

> "First thing in the morning, and then just after dark, the satellites that provided the signals would go out of range. As a result every morning and evening for about fifteen minutes we would get lost."[23]

Would a commander's entire force get hopelessly lost once the GPS signal disappears? Probably not, but the temptation to use GPS as a "crutch" looms large. For example, naval officers spend less time practicing celestial navigation today.[24] As GPS becomes the standard, will all forces use it as a "crutch?" U.S. Special Forces vow not to.[25] Special Operations Forces (SOF) use a variety of navigational methods to achieve their operational goals. GPS expands their capabilities as much, if not more, than other warfare specialties. Their insistence on not allowing GPS to become a "crutch" could be prophetic. The "crutch" of GPS could also effect the operational concept of *precision engagement* as GPS finds its way into more and more weapons systems.

Precision Engagement

General Rockwell's J-3 had the unenviable task of briefing him on current strike operations and the effects of GPS signal loss: "Well general, we're dropping the few unguided "dumb" bombs that we have. Soon we'll have to cut into our inventory of JDAM. At $40,000 a pop, they're an expensive iron bomb. The Standoff Land Attack Missile (SLAM) missions are scrubbed, because you can't launch one of those without satellite acquisition. We are back to 1991 on Tomahawk missions, that is, we have to rely on preplanned Cruise Missile Support Activity (CMSA) missions. GPS enhancements to that weapon's capability are null and void."

General Rockwell is encountering operational constraints in the execution of his plan.[26] He is experiencing the limitations of the "system of systems" without a critical component--

namely, GPS. GPS is an absolutely vital component of this conceptual system; especially in the *JV 2010* operational concept of *precision engagement.* The document's definition of *precision engagement* exudes lethality:

> "Precision engagement will consist of a system of systems that enables our forces to locate the objective or target, provide responsive command and control, generate the desired effect, assess our level of success, and retain flexibility to reengage with precision when required."[27]

Without GPS however, the capabilities described in this definition may prove elusive.

The Global Positioning System is already firmly entrenched in today's weapons systems and in those of future U.S. forces. John G. Roos of *Armed Forces Journal* writes: "...it [GPS] has become instrumental in defining the performance objectives of the services' latest precision-guided munitions."[28] As a result, a multitude of future U.S. military weapons systems rely on GPS in varying degrees.[29] The common thread of GPS running through so many weapons systems creates a critical vulnerability for the U.S. forces of 2010. To illustrate the pervasiveness of GPS, it is instructive to look at three examples from today's inventory: the Joint Direct Attack Munition (JDAM), the Standoff Land Attack Missile (SLAM), and the Tomahawk Land Attack Cruise Missile (TLAM). With the exception of JDAM, all three of these systems are in the inventory today. All are expected to be in the inventory in 2010. As Appendix B shows, the trend in precision weaponry heavily favors GPS. JDAM is a prime example.

JDAM is the "smart bomb" of the future. By 2010, the number of laser-guided bombs (LGBs) in the U.S. inventory will be very small, if not totally eliminated.[30] Why abandon the weapon that was the "technical hero" of Desert Storm, boasting a laudable circular error probable (CEP) of three meters or less?[31] The answer lies in a combination of tactical and economic considerations, but one thing is for sure; JDAM is the wave of the future.[32]

JDAM is composed of a Mk 83 (1,000 lb.), Mk 84 (2,000 lb.) or BLU-109 (2,000 lb. hard target penetrator) gravity bomb body and an INS/GPS fin guidance unit.[33] Using its

INS/GPS guidance system, it literally flies to a set of coordinates, achieving a CEP of 15 meters.[34] The USAF/USN JDAM program director, Terry Little admits that the GPS signal can be jammed. Should GPS guidance fail, accuracy suffers.[35] If the GPS signal is denied, JDAM's accuracy is no better than a "dumb" bomb--a CEP of 30-60 meters.[36] Aware of this vulnerability to jamming, the program office is vigorously pursuing protection of the weapon in a jamming environment.[37] In addition to anti-jamming technologies, increased accuracy is being sought for JDAM. The goal of the JDAM Product Improvement Program (JDAM PIP) is a three meter CEP--the accuracy of its predecessor, the LGB. JDAM PIP affixes a terminal seeker to the notional JDAM.[38] The problem? Cost. The debate continues whether to spend $40,000 on a notional JDAM, or $100,000 on a JDAM PIP.[39] JDAM program director Little summarized the debate succinctly: "It might be more attractive to adopt a policy of dropping three baseline JDAMs to insure a hit than to go ahead and equip them with expensive seekers."[40] As a rule, the more expensive a weapon is, the fewer there are available. A commander such as General Rockwell will surely not expend JDAM PIP rounds when there is no GPS available. With few or no LGBs available, he soon finds his precision strike capability constrained. The operational commander will also have to leave his SLAM missiles in the magazine should the GPS signal disappear or become unusable.

The Standoff Land Attack Missile (SLAM) enjoyed favorable reviews during DESERT STORM, mostly because of its precision standoff capability.[41] The Standoff Land Attack Missile Expanded Response (SLAM ER), an updated variant of the weapon will be available for General Rockwell's use in 2010. Eventually, 700 missiles will be delivered to the Navy, with production expected to continue until 2004.[42] SLAM ER has a greater standoff range than the missiles used in DESERT STORM, and delivers a stronger punch. In recent U.S. Navy testing of SLAM ER, an F/A-18 successfully engaged a land target from a range of 75 nm.[43] Tests

continue at greater ranges. McDonnell Douglas advertises a 150 nm standoff range from low level.[44] SLAM uses GPS signals to update its INS in the mid course guidance phase of flight. The SLAM variant used during the Gulf War required aircraft maneuvering to ensure satellite acquisition.[45] The new SLAM ER does not require such maneuvering, but still requires GPS data to ensure a hit.[46]. Even though SLAM ER's INS has very low drift rates, inertial guidance alone cannot guarantee target acquisition. SLAM ER's Honeywell INS is so "tight" that even if the GPS signal is denied for the last 80 nm of flight, the target will appear in the seeker field of view for terminal tracking.[47] Unfortunately, this presupposes that the missile had good GPS data prior to loss of signal, and relies on the low drift rates of the INS to ensure seeker acquisition. If GPS is denied from the very beginning of the mission, even SLAM ER's impressive equipment cannot guarantee success.[48] GPS is required for the accuracies necessary to place the target in the missile seeker field of view. The scenario is not as bleak for the operational commander when it comes to the Tomahawk Land Attack Missile (TLAM). TLAM will still be available in 2010, but if there is no GPS signal, the commander will have to rely on preplanned missions supplied by the Cruise Missile Support Activities (CMSAs).

The Tomahawk Land Attack Missile (TLAM) Block III upgrade uses INS, GPS and topographical matching techniques to achieve its navigation and terminal phase accuracy.[49] In Block III missiles, GPS tightens the terrain contour matching (TERCOM) navigation solution, and also introduces the possibility of reducing the number of TERCOM maps, or eliminating them altogether.[50] In earlier Blocks of the missile, only CMSA preplanned missions could be loaded into TLAMs. The advent of GPS technology will cause some of the planning responsibilities to shift from the CMSAs to the fleet. The CMSAs are specialized mapping agencies that digitize missions for downloading into TLAM mission memory.[51] They have an excellent reputation for responsiveness, but unfortunately they cannot plan all possible TLAM

targets. In the 1990s, the Afloat Planning System (APS) was introduced aboard aircraft carriers, allowing embarked APS detachments to conduct direct planning alongside the carrier's strike aircrew. GPS is essential for this process, allowing the shipboard planner the ability to edit existing missions or build new missions from scratch. In addition, GPS gives the Block III and IV missiles time-on-target capability, allowing for their close integration with fixed wing strike assets.[52] This enhanced capability provides flexibility for the operational commander of today. For the commander of 2010, who becomes accustomed to this capability, the lack of it becomes a constraint. Constraints come in many forms. Should the GPS signal disappear, the operational commander will find his supply flow constrained also.

Focused Logistics

J-4 passed the J-3 on his way to brief General Rockwell. He could tell by the look on the J-3's face that the briefing had not gone well. Upon reaching the General's office, the J-4 bypassed all small talk and began his briefing: "General, I don't have the location of the high profile cargo you requested because our tracking system requires GPS for position inputs. I am relying on message traffic to get position reports from the ships. It's crude, but it's all we have. In addition, our express air shipments are held up for two reasons. First, without GPS, the air traffic control system has to resort to manual separation procedures because ATC radars were eliminated by the early part of this century. Also, GPS precision approaches to airports are obviously unusable. And with that weather system on the east coast of the United States, we have a lot of grounded high priority cargo."

The *JV 2010* operational concept of *focused logistics* relies just as heavily on GPS as do the operational concepts of *dominant maneuver* and *precision engagement*. Once again, the definition of an operational concept hinges on the technologies involved:

> "Focused logistics will be the fusion of information, logistics, and transportation technologies to provide rapid crisis response, to track and shift assets even while enroute, and to deliver tailored logistics packages and sustainment directly at the strategic, operational, and tactical level of operations."[53]

GPS is an essential component of the architecture for this logistics vision of the future. Without GPS, the operational commander will not have the robust logistical capability described in *Joint*

Vision 2010. In fact, two areas of the logistics effort are significantly impacted by the lack of a reliable GPS signal: cargo tracking and delivery, and air traffic control.

The ability to track cargo in real time is central to the vision of *focused logistics. JV 2010* specifically addresses the ability to "track and shift assets even while enroute."[54] After the Gulf War, the Tracking, Command, Control and Communications System (TRACC3) was used to track sensitive items returning from the Gulf.[55] This system combines a GPS receiver with a laptop computer, battery and solar panel. It can be used to provide real time data regarding the supply status of high interest items. Although this system is used for high interest cargo today, it is the predecessor of the logistics tracking system of the future. Without GPS, this prototype of the future loses its real time tracking capability. Back up reporting methods must be employed. *Focused logistics* will become a bit less focused.

Once supplies finally reach the theater , they must still be distributed to the units that need them. GPS is just as valuable for this task as it is for *dominant maneuver.* Trucks delivering supplies in featureless terrain in 2010 will undoubtedly rely heavily on GPS for navigation. During Operation DESERT STORM precise positioning furnished by GPS allowed the coalition to deliver supplies to forward deployed units with efficiency and speed.[56]

The aviation branch of the logistics infrastructure relies very heavily on GPS. This trend will accelerate with time. The world views GPS as a low cost solution for the modernization of an overtaxed air traffic control (ATC) infrastructure. International air traffic is expected to increase at a rate of seven percent per year through the year 2007.[57] The use of a cost free signal for airways navigation and instrument approaches is very attractive economically.[58] It could drastically reduce a country's transportation infrastructure and therefore cut costs. In June 1994, the FAA cited GPS as the primary all weather navigation system for civil aircraft.[59] *Armed Forces Journal International* sees this as a world wide trend, not one isolated to the U.S.: "The

international civil airline authorities will soon follow the FAA's example, ensuring that civil aircraft around the world will soon be dependent on the U.S. and other GPS networks."[60] The Wide Area Augmentation System (WAAS) is a good example of this dependence on GPS. WAAS enhances GPS signals so that they may be used by civilian pilots as a primary means of navigation.[61] Additionally, GPS is increasingly being used for airfield instrument approaches. Because of the accuracies involved, only non-precision approaches are currently available.[62] However, the use of a technique called differential GPS (DGPS) can be used to increase the accuracy of the clear/acquisition (C/A) code.[63] Should DGPS be implemented, approximately 4,400 domestic airports would be able to implement precision instrument approaches.[64] While loss of the GPS signal threatens the operational concepts of *dominant maneuver, precision engagement,* and *focused logistics*, the presence of this same signal challenges the commander's ability to implement the concept of *full dimensional protection.*

Full Dimensional Protection

It was 0130. General Rockwell was leaving the command center when his J-2 caught up to him. "General, I have some good news and some bad news." "What is it, two?," replied the grumpy commander. "Well sir, the good news is that GPS is back up. We're not sure how, and neither is SPACECOM, but it is. The bad news is that we have received I&W of SCUD launches, and we are receiving reports of what appear to be cruise missile attacks on our logistics centers."

The operational commander of 2010 will really need his "system of systems" running smoothly, for his adversary will undoubtedly be armed with a variety of GPS systems. GPS technology has developed with incredible rapidity in recent years. Concurrently, the cost of receiver systems has plummeted. GPS is available and affordable for anyone--friend or foe. In the 1980s contractors boasted of the ability to squeeze a GPS receiver into a backpack. In September of 1996, SiRF Technology Inc. of Sunnyvale, California announced the availability of a GPS *chip-set* with the following capabilities:

> "The . . . [chip-set] supports 12 independent channels of satellite data, each capable of signal reacquisition in one-tenth of a second. In addition, the processors include multi-path signal

> rejection--important when attempting to operate the GPS unit in the canyon between tall buildings--and the ability to function with signals weakened by foliage environments."[65]

The Journal of Electronic Defense wryly notes that this type of technology could make the GPS dog collar a reality.[66] While the potential enemies of 2010 may not want to purchase GPS dog collars, they will embrace this technology--and at bargain basement prices. The SiRF chip-set mentioned above costs approximately $50 per unit when purchased in original equipment manufacture (OEM) quantities.[67] This is a far cry from the $50,000 price tag of bulky, early model NAVSTAR receivers.[68]

What does all of this mean? It means that even an enemy without access to the highly accurate P-code will be able to produce a fairly significant offensive military capability.[69] There are three reasons that the operational commander of 2010 needs to be concerned about the effects of GPS proliferation on the operational concept of *full dimensional protection*: the commercially available GPS signal is more accurate than originally expected; differential GPS (DGPS) technology can deliver better accuracies than the military Precise Positioning Service (PPS), and inexpensive GPS-guided cruise missiles will abound in the battlefield of 2010.

Accuracy has always been an essential element of GPS. The system had its origins in the 1960s as a spin-off of the TRANSIT space-based radionavigation satellite system, used for the Navy's Polaris submarine fleet in the 1960s. Up until the early 1980s, being "too accurate" with GPS data was not a concern, as GPS was a purely military system -- although its potential civilian applications were clearly understood. The shootdown of Korean Air Lines Flight 007 in 1983 changed all of that, however. The incident acted as a catalyst for President Reagan's official declaration of GPS as a dual-use system that would be made available to the world, free of charge, through the Department of Transportation (DoT).[70] The Standard Positioning Service (SPS) is the GPS product intended for worldwide commercial use. DoD considered accuracy as a security issue in its design, but was outflanked by the electronics industry:

> "When designing the GPS system, the U.S. Department of Defense intended that the SPS should provide a positional accuracy of no better than 100m. Commercial C/A-code receivers routinely produce read-outs that are accurate up to 20-40m, however, allowing them to be militarily useful."[71]

Not only do unaided receivers exceed the capabilities envisioned by DoD, the advent of differential GPS (DGPS) technology further challenges the operational commander's ability to implement the operational concept of *full dimensional protection.*

Differential GPS technology, like most advances in GPS, was spurred by the civilian marketplace. Unhappy with the accuracy of degraded GPS signals, caused by DoD's use of Selective Availability (SA), civilians sought a more accurate GPS position solution.[72] One of the solutions to this predicament is differential GPS (DGPS). DGPS uses a receiver site with a precisely surveyed location to evaluate GPS signal error. The surveyed site receives GPS signals (that will contain various errors, including SA) and compares the difference between the GPS solution and its precisely surveyed position. The site then transmits a correction signal to the GPS receiver, resolving the signal errors.[73] Accuracies of one to five meters are typical when this technique is used.[74] Accuracies furnished by the Precise Positioning Service (PPS) -- the U.S. military signal--are typically between *eight and eighteen meters.*[75] Therefore, a foe with DGPS capability can possess more accurate GPS data than a U.S. military unit receiving the P-coded signal. DGPS *does* have its limitations. Its chief limitation is range. Since the user receiver and the DGPS reference receiver need to be looking at the same set of satellites, DGPS range is considered to be limited to 500-600km.[76] Enter wide-area DGPS (WADGPS). This system uses satellites to funnel information from many DGPS ground reference sites to a central processing facility. DGPS corrections are broadcast to GPS customers within range of any of the local reference stations, thus potentially spreading the effectiveness of DGPS over an entire continent--or theater of operations.[77] The existence of accurate DGPS in and of itself is not

dangerous, but its potential application is. *Jane's Defense Weekly* eloquently describes the link between DGPS and the cruise missile threat:

> ". . . the fear is that DGPS can also provide valuable targeting information for a Third World Nation that has strapped a GPS receiver to a cruise missile. While a ballistic missile might travel too fast for commercial GPS systems to be of any use, cruise missiles are much slower. Given the element of surprise or numbers, Third World Cruise missiles could pose a serious threat."[78]

Cruise missiles that use DGPS for targeting information are potent strike assets. The accuracies provided by DGPS could afford the innovative foe the opportunity to strike U.S. logistics centers and other critical military nodes. The operational commander of 2010 will have to contend with such weapons *and* with GPS-guided ballistic missiles, not to mention GPS-guided cruise missiles that carry weapons of mass destruction (WMD) payloads.[79]

Currently, treaty restrictions, such as those imposed by the Missile Technology Control Regime (MTCR), make access to ballistic missile GPS technology difficult.[80] Could ballistic missile GPS technology leak out by 2010? RAND Corporation analyst Irving Lachow thinks so: ". . . it is certainly possible that some GPS receivers will find their way onto Third World ballistic missiles in the next decade."[81] Should this occur, a reduction in CEP is sure to follow. Whittling down the SCUD's 1000m CEP would transform this terror weapon into a military one.[82] Dr. Arthur Knoth of *International Defense Review* points out that regardless of the small conventional warhead size associated with the *Al Hussein* SCUD missile (only 227 kg or 500lbs. TNT equivalent), its destructive kinetic energy is equal to 300 kg (660 lbs.) of TNT.[83] Dr. Knoth makes the astute observation that reducing the CEP of a missile such as the *Al Hussein* to 200 meters or less by using GPS technology would give it military capabilities.[84] Should the reduction in CEP take place, the weapon, which in its present form has a range of 650 km (354 nm), could be very effective against logistics centers, garrisoned troops, or any area where there is a concentration of military personnel or material. While SCUD missiles require unique GPS

technology, GPS-guided WMD cruise missiles can use commercially available receivers to achieve their desired CEP.

WMD cruise missiles are of great concern to the operational commander today, and will be an even greater concern in 2010. In the document *Proliferation: Threat and Response*, the commanders in chief of the unified geographic commands (CINCs) made cruise missile interception their number two priority (second only to chemical and biological agent detection capability):

> "The . . . [second] CINC priority is the ability to intercept cruise missiles...These capabilities are particularly relevant for counterproliferation because cruise missiles are an extremely effective delivery system for BW [biological weapon] and certain CW [chemical weapon] attacks."[85]

The CINCs understand that GPS signals provided by SPS are more than adequate to guide GPS aided WMD cruise missiles to their targets.[86] GPS can be of great concern to the commander when its friendly use is denied, or the enemy's use is maximized. The CINC of today can help minimize these effects for the CINC of 2010, however.

Recommendations

The operational commander of today can take steps to ensure that the CINC of the future will not experience the nightmare scenario of General Rockwell:

Training. Insist on training that stresses fundamentals--especially in the areas of navigation and weapons employment. Ensure that soldiers and sailors who navigate on the ground; in the air, and on or below the sea can still get the job done without a "little black GPS box." Identify constraints and workarounds. Also, train like you fight. As an operational commander, "pull the plug" on GPS early in war games. Learn from the effects it has on your warfighting capability.

Planning. Query assumptions about potential interference with, or denial of GPS signals in your AOR. Although the former Soviet Union is the only country to have gone public with an anti-satellite capability, does that mean that a large country in your theater has no capability?[87] Use

your intelligence officers to look hard at this potential. Recommend revisions of the Joint Strategic Capabilities Plan (JSCP) planning assumptions where it is appropriate.

Acquisition. Since the ultimate objective of the Planning, Programming, and Budgeting System (PPBS) is ". . . the acquisition and allocation of resources to meet the warfighting needs of the combatant commanders," the commander needs to identify shortfalls in capability.[88] Should the aforementioned training and planning processes identify a vulnerability resulting from a heavy reliance on GPS systems, then it is incumbent upon the commander to propose alternatives. This will not be popular, as GPS is technology "on the cheap," but the cost of not identifying this shortcoming is far greater.

Conclusion

GPS is a powerful technology. When employed as envisioned in *Joint Vision 2010*, it will allow the operational commander to swiftly defeat the enemy with minimal casualties. But when an uncooperative foe decides to deny the U.S. access to the GPS signal, *JV 2010's* vision is not so clear. The concept of *dominant maneuver* bogs down, as vehicles of all types resort to back up navigation--which may or may not have been practiced in training. Identifying friend from foe on the battle field becomes difficult, as the GPS-based system ceases to function. *Precision Engagement* becomes an exercise in resource management, as the commander sorts through his weapon inventory for a system that is not GPS dependent. *Focused Logistics* fails to meet its "know where every package is at all times" reputation because of the lack of GPS-based tracking systems. Air carriers will be slowed, at best, in an environment where all civil air navigation relies on GPS signals. Should a future conflict leave the GPS signal up and running, then the commander of 2010 has another problem--*full dimensional protection*. The SCUD missiles that were once only terror weapons may home in on logistics infrastructure. Cruise missiles are certain to abound. GPS guidance coupled with low observability make them a

viable threat, regardless of the payload. GPS could be the savior or the bane of *Joint Vision 2010*. If we are honest about our vulnerabilities, perhaps we can avoid being cut by the very sharp blade of the GPS "double-edged sword."

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[1] Milan N. Vego, "Operational Art." (Draft Textbook, U.S. Naval War College, Newport, RI: 1997), 7.
[2] Joint Chiefs of Staff, Joint Vision 2010 (Washington: 1995), 17.
[3] Ibid., 1.
[4] Ibid., 13.
[5] Admiral William A. Owens, "The Emerging System of Systems," Proceedings, May 1995, 38.
[6] For a description of the Global Positioning System, please see Appendix A.
[7] The current constellation of 24 Block IIA satellites was completed on 9 March 1994. The replacement of Block IIA satellites with Block IIR is underway. The first launch of a Block IIR satellite took place on 27 March 1996. Block IIR replacements will continue until 2009. Block IIF will replace the Block IIR constellation; this new block will be operationally available in the years 2001 - 2010. The projected life expectancy of a Block IIF satellite is 12.7 years; Don Herskovitz, A Sampling of Global Positioning System Receivers," Journal of Electronic Defense, May 1997, 58.
[8] Owens, 38.
[9] In order to understand GPS in the context of a **critical vulnerability**, another term of operational art must first be defined; **critical weakness**. A critical weakness is "a capability that while vital, is qualitatively or quantitatively inadequate by itself to ensure the accomplishment of a given directive. A critical weakness can become a critical vulnerability if it is directly related to the enemy's center of gravity and potentially open to attack by one's own and friendly forces." Since GPS is an integral component of all facets of *JV 2010* forces, and is potentially open to attack, it is a critical vulnerability for the operational commander; Vego, 121.
[10] Don Herskovitz, "And the Compass Spun Round and Round: The Coming Era of Navigation Warfare," Journal of Electronic Defense, May 1997, 37-38.
[11] GPS lies above the anti-satellite system of the former Soviet Union. Thus far, the former USSR is the only country to publicly declare an anti-satellite capability; Doug Richardson, "Global Positioning System Versus Gyro," Armada International, no. 5 (1993): 44.
[12] Joint Chiefs of Staff, 20.
[13] Ssgt. William H. McMichael, "The Army's Newest Toy," Soldiers, December 1991, 30.
[14] Ibid.
[15] Mark Hewish, "GPS Meets New Challenges," International Defense Review, no. 10 (1995): 62.
[16] "INS compensates for GPS's susceptibility to jamming, sensitivity to vehicle manoeuvres [sic], velocity errors, and satellite acquisition and re-acquisition times. In turn, GPS aids INS to reduce propagation of errors with time, uncompensated sensor errors, and the in-air alignment time of tactical weapons."; "Rockwell's Evolutionary Approach to Integrated INS /GPS," International Defense Review (Defense Electronics and Computing Supplement), no. 12 (1992): 1209.
[17] Mark Tapscott, "Extending GPS on Land, Sea and Air," Defense Electronics, July 1993, 42.
[18] Joint Chiefs of Staff, 20.
[19] Owens, 37.
[20] Hewish, 60.
[21] The Situational Awareness Beacon with Reply (SABER) system is referred to here. As of 1995, it was under development by the U.S. Naval Space Command in partnership with the Joint Command and Control Warfare Center; Ibid.
[22] Ibid.
[23] Will Fowler, "Land Based Global Positioning Systems," Asian Defense Journal, no. 12 (1996): 31.
[24] John M. Stewart, "Modern Navigation in the Era of GPS," Naval Forces, no. 4 (1994): 55.
[25] Michael Jenne, "Applying GPS to Special Operations," National Defense, December 1990, 22.

[26] An operational constraint obligates the operational commander to follow certain military courses of action; Vego, 213.
[27] Joint Chiefs of Staff, 21.
[28] John G. Roos, "High Stakes Contract 'Winner-Takes All' Outcome Likely From Air Force's GPS Satellite Plan," Armed Forces Journal International, October 1995, 64.
[29] See Appendix B for a sampling of these weapons systems.
[30] Although JDAM is expected to replace the Paveway series of laser-guided weapons in the inventory, there is no firm date for the replacement. As long as there are laser capable platforms in the inventory (i.e., F-15E, F/A-18, F-117...et al), there will be LGBs available; Clifford Beal, Mark Hewish and Bill Sweetman, "Bolt from the Blue Part 2," International Defense Review, no. 12 (1992): 1177.
[31] Seemingly every night on CNN, the world watched LGB footage of incredibly accurate target destruction. The LGBs circular error probable (CEP)--i.e., where 50% of a given number of LGBs will fall--is equal to or less than three meters. Beal and Sweetman actually credit LGBs with a CEP of one meter or less; Clifford Beal and Bill Sweetman, "Bolt from the Blue; Standoff Weapon Developments," International Defense Review, no. 8 (1992): 758.
[32] The delivery of a laser-guided weapon requires the attack aircraft to "lase" the target continuously until impact. Some systems have automatic trackers, and some do not. Either way, the limited maneuverability of the aircraft during delivery, combined with limited standoff capability put the attack aircraft and crew at risk during the terminal delivery phase of an attack. Economically speaking, the USAF also decided that it was cheaper to pursue JDAM than to retrofit their B-1, B-2, and B-52s with laser designators; Beal, Hewish, and Sweetman, 1174.
[33] "Doubts remain over GPS for JDAM," Jane's Defense Weekly, 18 June 1994, 44.
[34] For a definition of CEP, see note 31. An accuracy of 15m is attributed to the "notional" JDAM package. That is, a JDAM round with no terminal seeker: Beal, Hewish, and Sweetman, 1173.
[35] "Doubts remain over GPS for JDAM," 44.
[36] Beal, Hewish, and Sweetman, 758.
[37] In May of 1994, planning was underway for the anti-jam GPS technology flight test (AGTFT); "Doubts Remain Over GPS for JDAM," 44.
[38] A variety of technologies are being pursued for the terminal seeker system: imaging infrared (IIR); millimetric wave (MMW); synthetic-aperture radar (SAR); anti-radiation, and laser-radar (LADAR); Beal, Hewish, and Sweetman, 1173.
[39] Ibid., 1174.
[40] "Doubts Remain Over GPS for JDAM," 48.
[41] SLAM is a hybrid of the Harpoon anti-ship missile and the Maverick air-to-ground missile. A Maverick imaging infrared receiver (IIR) seeker is mated to a Harpoon missile body and an upgraded guidance section (INS/GPS). In the terminal phase of flight, the weapon uses a Walleye man-in the-loop data link for discrete targeting capability; "Sea SLAM -- Standoff Land Attack Missile," 1997, <http://www.boeing.com/defense-space/missiles/slam/seaslam.html> (29 January 1998).
[42] Patricia Frost, "McDonnell Douglas Delivers SLAM ER to U.S. Navy," December 17, 1996, <http://www.boeing.com/news/releases/mdc/96-319.html> (29 January 1998).
[43] Grand SLAM ER," Aviation Week and Space Technology, 19 January 1998, 13.
[44] Ibid.
[45] The A-6E SLAM checklist required satellite acquisition for preplanned missions. A series of aircraft turns were required to achieve acquisition. A System Advisory Code (SAC) of 217, meaning "selected SLAMs have valid mission select, good satellite acquisition," was required following the satellite acquisition maneuver, and before proceeding with the checklist; Navy Department, Tactical Manual Pocket Guide: A-6 Aircraft, NWP 55-3-A6 PG (Rev. E) (Washington, 1992), 92.
[46] In the F/A-18 for example, the SLAM ER starts navigating as soon as power is applied to the aircraft by communicating with the aircraft's 1760 data bus. Additionally, the new missile uses a multi-channel GPS receiver, as opposed to the single channel receiver used by the original SLAM; Rob Freedman, SLAM ER program manager, telephone conversation with author, 30 January 1998.
[47] SLAM ER uses a Honeywell 1320 laser ring gyro INS; Ibid.

[48] Ibid.
[49] TLAM first uses INS navigation to make landfall. Next, it uses terrain contour matching (TERCOM) map sets to navigate to the target. TERCOM uses a map matrix which compares missile radar altimeter information to a digitized terrain data base. A voting algorithm is used to "match" the altimeter and data base information for navigation updates. TERCOM accuracy is sufficient for navigation, but greater accuracy is required for the terminal phase of flight. Digital scene matching area correlator (DSMAC) is used for terminal homing. Using the missile's electro-optic sensor, DSMAC compares successive images of the terminal path leading to the target site. The correlation of grey-scale high resolution picture images with the onboard data base provide precise position updates to the missile in the terminal phase of flight; Eric V. Larson, Technological Risk: The Case of the Tomahawk Cruise Missile, (Santa Monica: The RAND Graduate School, 1990), 18-23.
[50] Tapscott, 43.
[51] One CMSA is located in Norfolk, VA, the other in Honolulu, HI; Robert Schlagel, Atlantic Fleet APS Detachment Commander, telephone conversation with author, 30 January 1998.
[52] Peter Castor, USACOM CMSA, telephone conversation with author, 30 January 1998.
[53] Joint Chiefs of Staff, 24.
[54] Ibid.
[55] Mark Hewish, "GPS Users Proliferate Following Gulf War," International Defense Review,(Defense Electronics and Computing Supplement), no. 9 (1992): 115.
[56] Bruce Buckland, "Temporary Glut Slows Military GPS Procurement," Defense Electronics, March 1992, 50.
[57] Irving Lachow, "The GPS Dilemma: Balancing Military Risks and Economic Benefits," International Security, Summer 1995, 131.
[58] It is U.S. policy to provide the Standard Positioning Signal (SPS) free of charge to everyone in the world; The White House Office of Science and Technology Policy, U.S. Global Positioning Policy Fact Sheet (Washington: March 29, 1996), 2.
[59] Neil Munro, "The GPS Network: Everybody Wants a Slice," Armed Forces Journal International, August 1994, 18.
[60] Ibid.
[61] Ibid.
[62] Non-precision approaches do not allow aircraft to descend as low on approach as do precision approaches. Therefore, a precision approach is preferable in bad weather, where cloud ceilings are lower and visibility is more restricted. The classification of an approach as precision or non-precision is directly related to the accuracy of the equipment used in the approach; Kitty Pultorak, Aircraft Owner's and Pilot's Association (AOPA), telephone conversation with author, 2 February 1998.
[63] For a review of GPS signals, see Appendix A. For a detailed discussion of DGPS, please see the *Full Dimensional Protection* section of this paper.
[64] Lachow, 131.
[65] Herskovitz, "And the Compass Spun Round and Round," 36.
[66] Ibid.
[67] Ibid.
[68] Stewart, 55.
[69] For an explanation of various GPS signal types, please see Appendix A.
[70] Lachow, 127.
[71] Hewish, "GPS Users Proliferate Following Gulf War," 116.
[72] For a detailed discussion of GPS signals, please see Appendix X.
[73] Lachow, 129.
[74] Ibid.
[75] Hewish, "GPS Users Proliferate Following Gulf War," 116.
[76] Lachow, 129.
[77] Ibid., 130.
[78] "GPS: Waiting for a Clear Signal," Jane's Defence Weekly, 16 November 1991, 949.

[79] For the purposes of this paper, WMD comprises biological or chemical payloads. Although nuclear weapons are considered part of WMD, nuclear capable cruise missiles are less likely to be used by Third World foes; mainly because of cost.
[80] GPS receivers capable of functioning at speeds in excess of 515 km/sec (1854 km/hr or 1308 kts) and at altitudes in excess of 18 km (9.8 nm) are restricted by the MTCR; Lachow, 137.
[81] Ibid., 137.
[82] Arthur Knoth, "GPS Technology and Third World Missiles," International Defense Review, no. 5 (1992): 414
[83] .Ibid.
[84] Ibid.
[85] Office of the Secretary of Defense, Proliferation: Threat and Response (Washington, April 1996), 49.
[86] Lachow, 135.
[87] Richardson, 44.
[88] Joint Chiefs of Staff, Doctrine for Planning Joint Operations (Joint Pub 5-0) (Washington: April 13, 1995), II-2.

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APPENDIX A

GPS COMPONENTS AND TERMINOLOGY

Components

GPS satellites - "The satellites are deployed in a 10,900 nm circular orbit with a 12 hour period. Four satellites are located in each of the six planes inclined at 55 degrees to the plane of the Earth's equator. Each satellite continuously broadcasts pseudorandom codes on two frequencies, L1 at 1575.42 MHz and L2 at 1,227.6 MHz. L1 is modulated with two types of code, the C/A, or coarse/acquisition, and the P, precision code. L2 carries only the P code."[1]

GPS ground stations - "The network of ground stations consists of monitors at widely spaced, precisely known locations. Transmissions from the satellites are received and data forwarded to the master station, where this data is analyzed and the GPS time and universal standard time are compared. The master station prepares signal-coding corrections and change orders for the satellite control facility, which uploads data to the satellites."[2]

GPS receivers - The receivers use the continuously transmitted navigation and timing signals of the satellites to calculate three-dimensional (latitude, longitude, and altitude) location, velocity and time for any point on the Earth's surface.[3]

Terminology

C-Code - Also known as C/A, or coarse acquisition code. This code is available for commercial users.[4]

P-Code - Also known as PP code, is the precise positioning code available to military customers.[5]

PPS - Precise positioning service; the service that provides the more accurate P-code.[6]

SA - Selective Availability; dithers the C/A code by introducing errors into the signal, hence making it less accurate. This error was devised to protect U.S. national security interests.[7]

SPS - Standard Positioning Service; the civil and commercial service provided by the basic GPS.[8]

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[1] Don Herskovitz, "A Sampling of Global Positioning System Receivers," Journal of Electronic Defense, July 1996, 57.
[2] Ibid.
[3] Mark Tapscott, "Extending GPS on Land, Sea and Air," Defense Electronics, July 1993, 42.
[4] Ibid.
[5] Ibid.
[6] Ibid.
[7] Irving Lachow, "The GPS Dilemma; Balancing Military Risks and Economic Benefits, "International Security, Summer 1995, 129.
[8] "US Reviews GPS Policy," Military Technology, no. 5 (1996): 8.

APPENDIX B

GPS-GUIDED WEAPONS SYSTEMS[1]

WEAPON	SERVICE	GUIDANCE
GLOBAL POSITIONING SYSTEM AIDED MUNITIONS (GAM)	USAF	GPS/INS
JOINT DIRECT ATTACK MUNITION (JDAM)	USAF/USN	GPS/INS
JDAM PRODUCT IMPROVEMENT PACKAGE (PIP) - JDAM PIP	USAF/USN	GPS/INS W/TERMINAL SEEKER
JOINT STANDOFF WEAPON (JSOW) THREE VARIANTS: BASELINE, BLU-108, UNITARY (AGM-154A/B/C RESPECTIVELY)	USN/USAF (AGM-154C USN ONLY)	A - GPS/INS B - GPS/INS; BLU-108 SUBMUNITIONS USE INFRARED TERMINAL SENSOR C - GPS/INS; TERMINAL SEEKER WITH MAN-IN-THE-LOOP DATA LINK
THEATER HIGH ALTITUDE AREA DEFENSE (THAAD)	USA	INERTIAL, GPS, COMMAND WITH IR
STANDOFF LAND ATTACK MISSILE (SLAM)	USN	INERTIAL, GPS, IIR, MAN-IN-THE-LOOP DATA LINK
TOMAHAWK LAND ATTACK MISSILE (TLAM): TLAM-C; UNITARY WARHEAD TLAM-D; DISPENSED BOMBLETS	USN	INERTIAL, GPS (BLOCKS III AND IV), TERCOM, AND DSMAC

[1] Wayne F. Sweitzer, "Battlespace Information, Command and Control (C2), Operational Intelligence, and Systems Integration," (U.S. Naval War College, Newport, RI: 1997), 31-38.